PhotoSensors for sPHENIX Calorimeters

SPHENIX CALORIMETER ELECTRONICS REVIEW

25-MARCH-2015

S. STOLL

HCal and EMCal

EMCal –

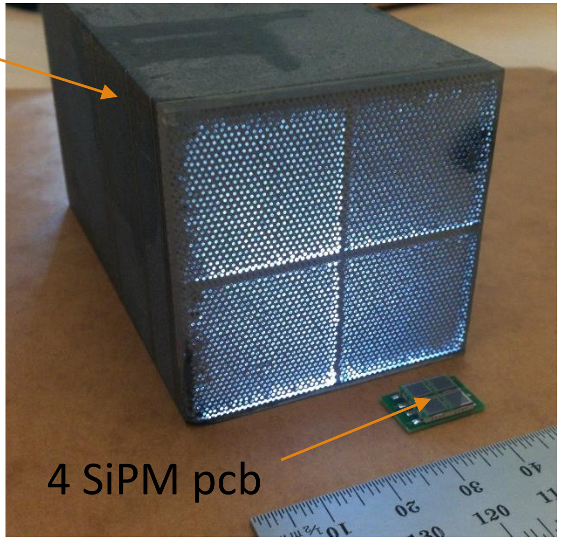
Tungsten Powder / Scintillating fiber absorber
450nm light from Kuraray SCSF-78 fibers,
approx. 500 photoelectrons per GeV collected on 4 sipms (36mm^2 active area)
each readout tower/channel is a 22 x 22 x 130mm^3 block
1 light guide per tower with 4 sipms
4 sipms are passively summed into one preamp FEE channel
24,576 readout channels, **98,304** sipms total

HCal (Inner and Outer) –

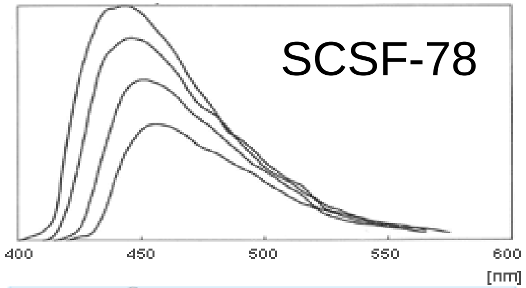
Steel plates / Plastic scintillator plates with embedded wavelength shifting fibers
476nm light from Kuraray Y-11 fibers
1 sipm per tile reading out 2 ends of a 1mm diameter fiber loop
5 tiles - 5 SIPMs passively summed into 1 readout channel
3072 total readout channels
15,360 SIPMs : 7680 (Inner HCal) + 7680 (Outer HCal)

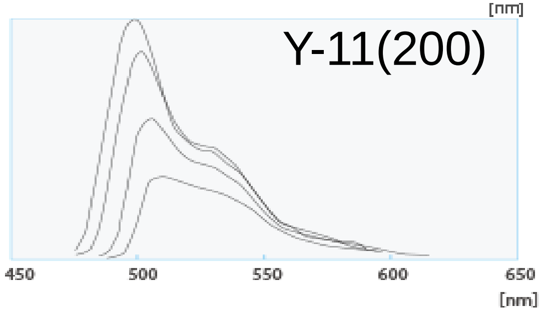
98,304 + 15,360 = ~ **113,664** total SIPMs

W-scint SPACAL module
(O. Tsai)



Fiber emission spectra:





Device Considerations

- Must operate in a 1.5 T magnetic field
- Limited radial space – EMCal ~ 7.5 cm for photosensor, FEE board, cables
  Inner HCal ~5 cm
- Dynamic range: 4 orders of magnitude 10 MeV to 50 GeV (max ~40 Gev / tower)
- SIPM dynamic range is limited by the number of u-pixels, and due to optical saturation effects the full pixel range cannot be used. We need >10,000 u-pixels per device
- Gain 10^5 – 10^6
- Sensitivity – Photon Detection efficiency > 20%
- Area coverage – In EMCal light is distributed over 22mm x 22mm readout surface. Some efficiency gained through light guide, but it is cost prohibitive to cover entire surface
- Thermal stability: gain vs temp, dark count rate vs temperature
- Radiation Hardness: expected neutron exposure ~ 2×10^{10} /cm^2 per run year in sPHENIX

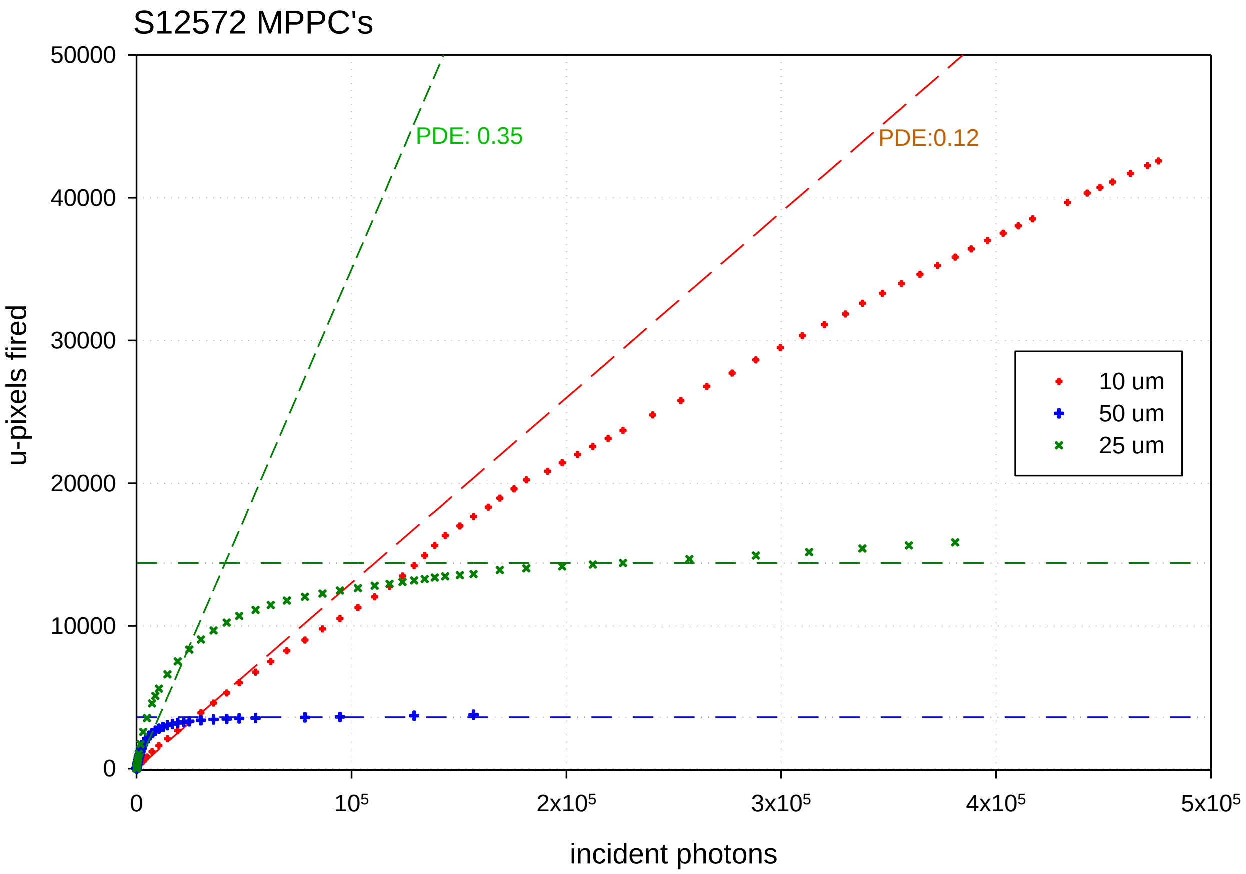
Sipms studied

manufacturer	model	microcell size (um)	active area dim (mm^2)	total # microcells	gain	PDE (%)	dark current (nA)
Hamamatsu	S10931-025P	25	3x3	14400	2.75E+05	20	100
	S12572-010P	10	3x3	90000	1.35E+05	10	15
	S12572-015P	15	3x3	40000	2.30E+05	25	20
	S12572-025P	25	3x3	14400	5.15E+05	35	80
	S12572-050P	50	3x3	3600	1.25E+06	35	350
SensL	MicroFC30020	20	3x3	10998	1.00E+06	24	85
	MicroFC30035	35	3x3	4774	3.00E+06	31	250
	MicroSL-10050-x13	50	1x1	3600			
AdvansID	ASD-SiPM3S-P-50	50	3x3	3600	2.50E+06	22	2000
KETEK	PM3350	50	3x3	3600	8.00E+06	50	260
Excelitas	C30742CERH-50-3-1	50	3x3	3600	1.50E+06	30	700
	C30742CERH-25-1-1	25	1x1	400			

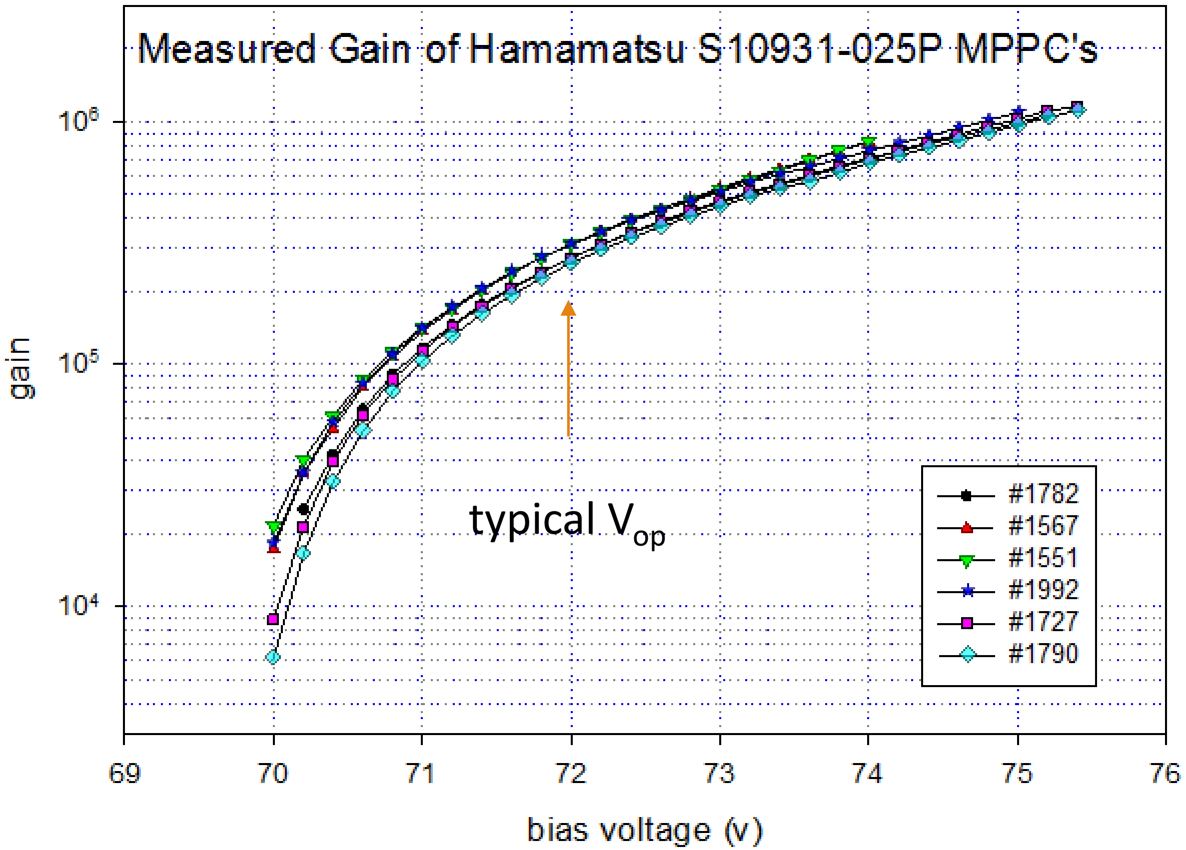
(Data collected from manufacturer’s device data sheets)

Optical saturation

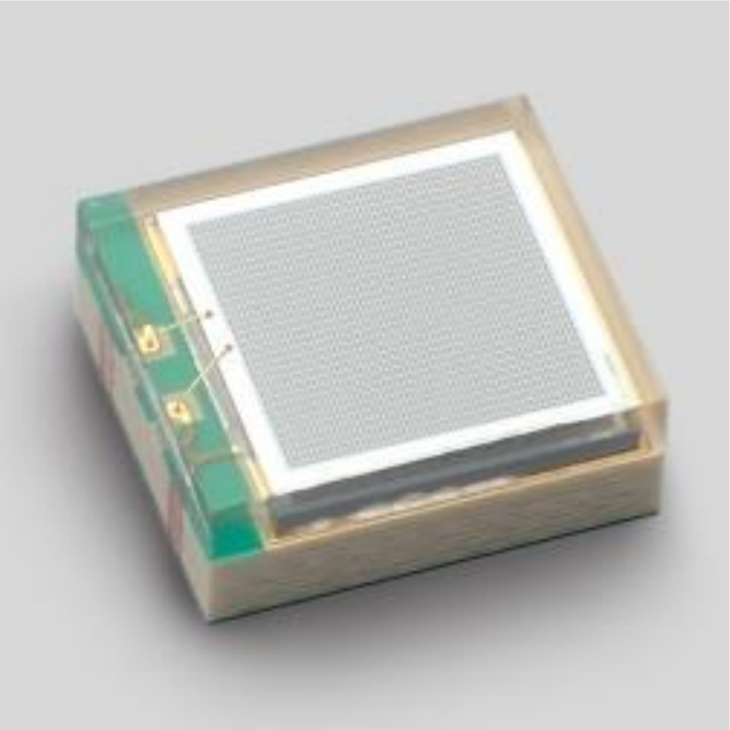
Dynamic range is limited by number of microcells in device



Gain vs V_{bias}



Hamamatsu S12572 -015P Specifications



Effective photosensitive area	3 × 3 mm
Pixel pitch	15 µm
Number of pixels	40000
PDE	0.25
Number of channels	1 ch
Package	Surface mount type
Cooling	Non-cooled
Spectral response range	320 to 900 nm
Peak sensitivity wavelength (typ.)	460 nm
Dark count (typ.)	1000 kcps
Terminal capacitance (typ.)	320 pF
Gain (typ.)	2.3×10^5
Recommended operating voltage (typ.)	V_{BR} + 4.0 V
Measurement condition	Ta=25 ℃

(Data from manufacturer's device data sheet)

Unit price (quantity 120k) = $8.50 x 120,000 = $1.02M

SensL SiPMs output pulses

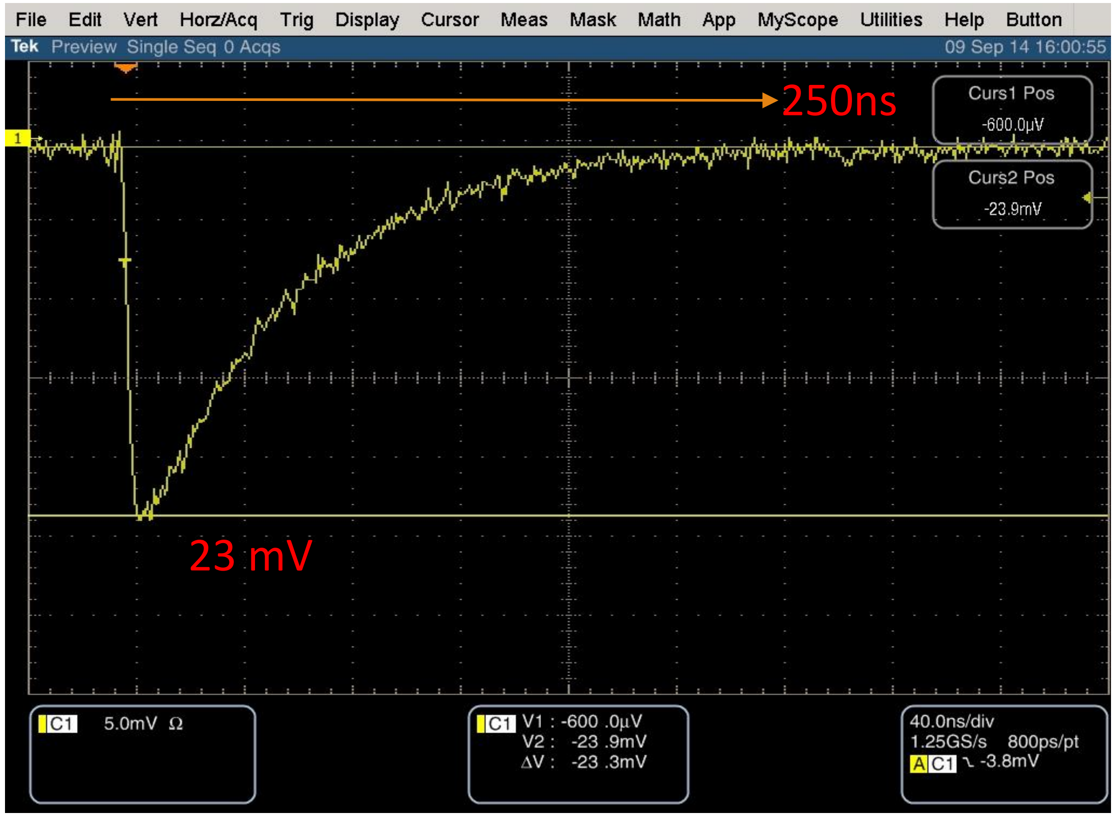
~1000 incident photons / pulse, 420nm LED (~2 GeV equiv)

No preamp / shaper - passive bias ckt into 50 ohm oscilloscope input

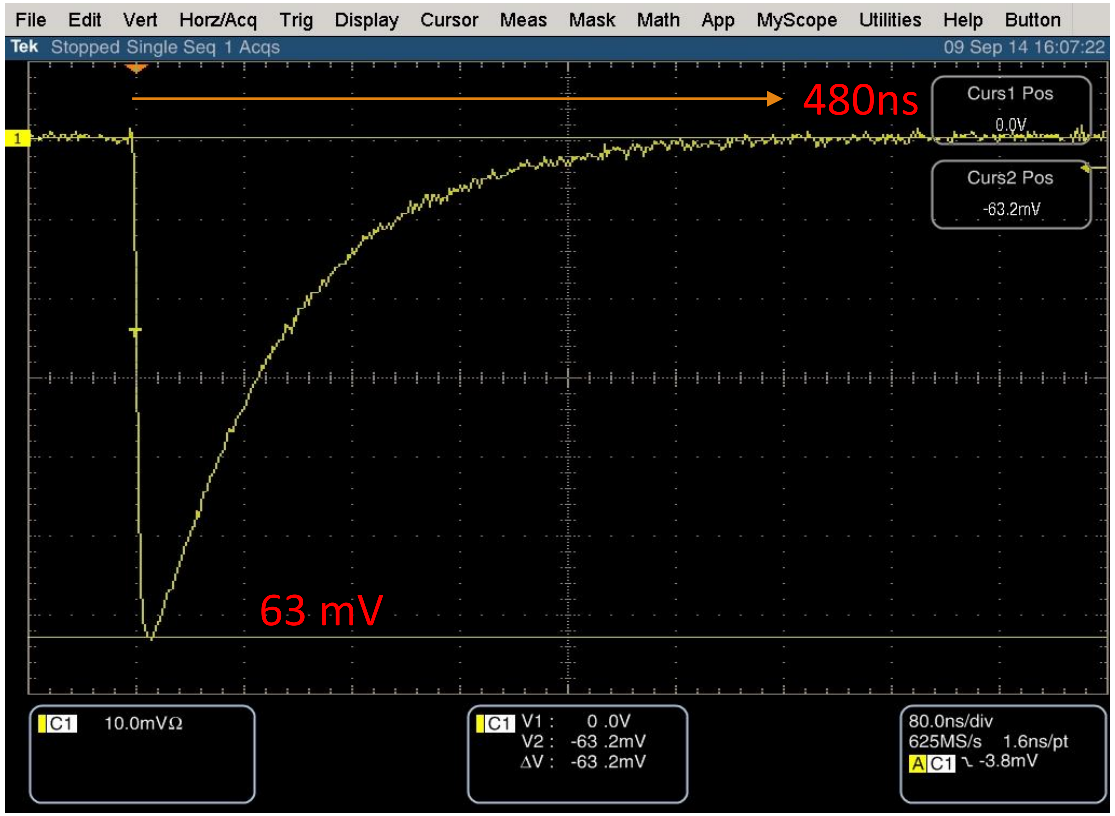
Both biased at 27.15V

SensL FC-30020 (left) and FC-30035 (right)

Gain: $1x10^6$, PDE: 0.24

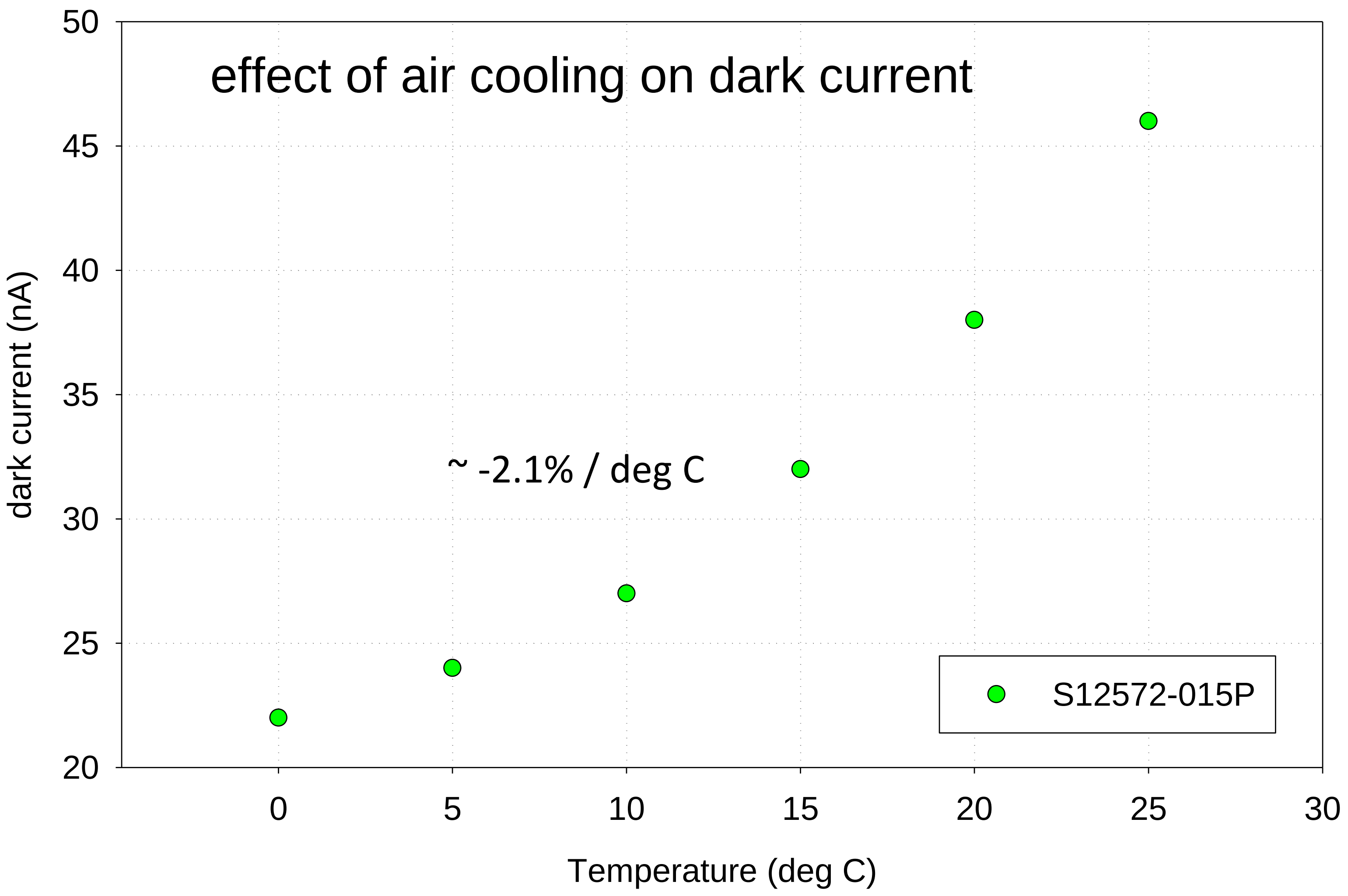


Gain: $3x10^6$, PDE: 0.31

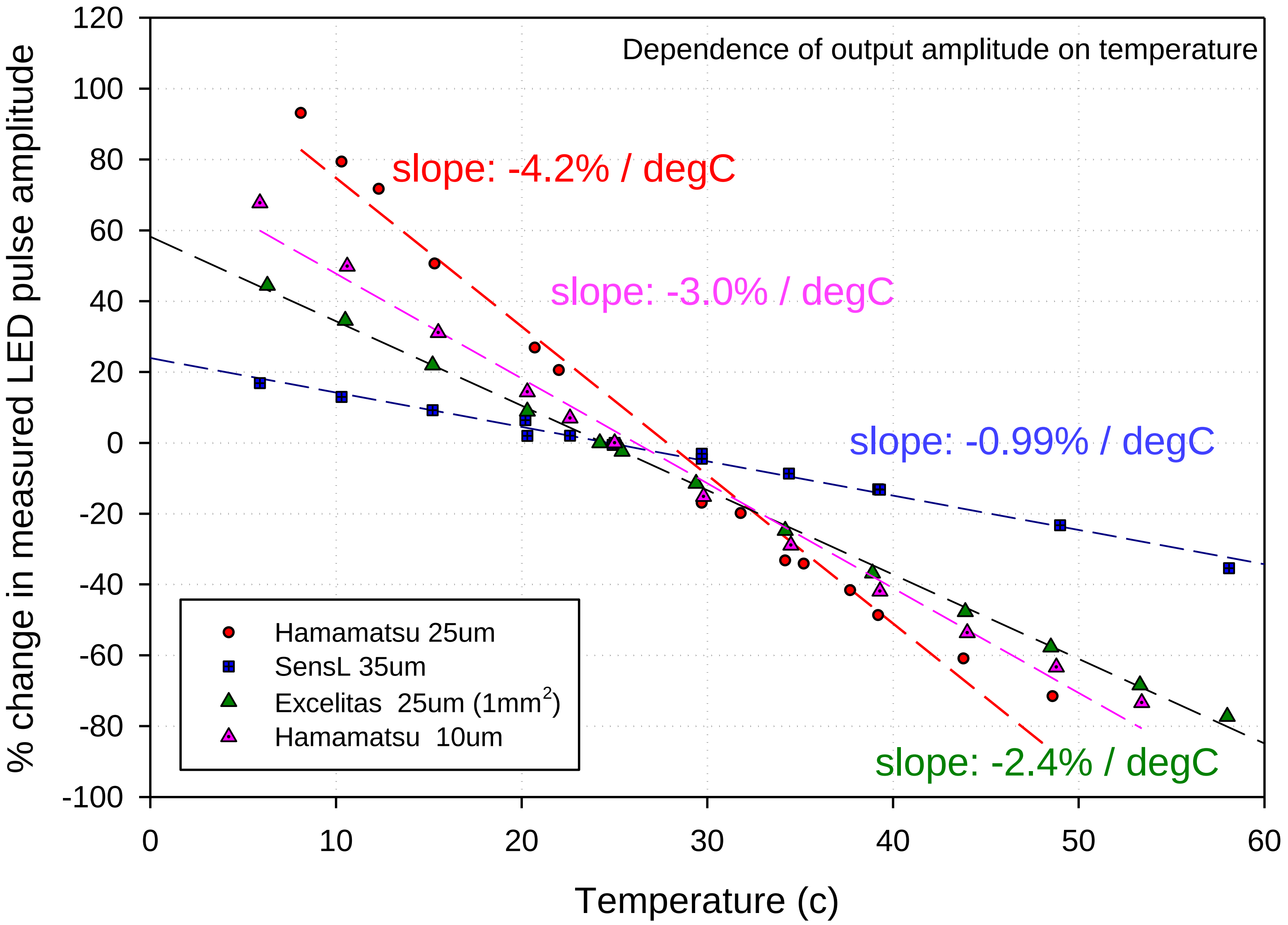


Thermal Issues

- Dependence of gain on temperature
- Thermal noise – Dark current, dark count rate



Air cooling reduces the dark current by about 2% per degree C.



SIPM output signal decreases with increasing ambient temperature (~4% / degC for Hamamatsu SIPMs).

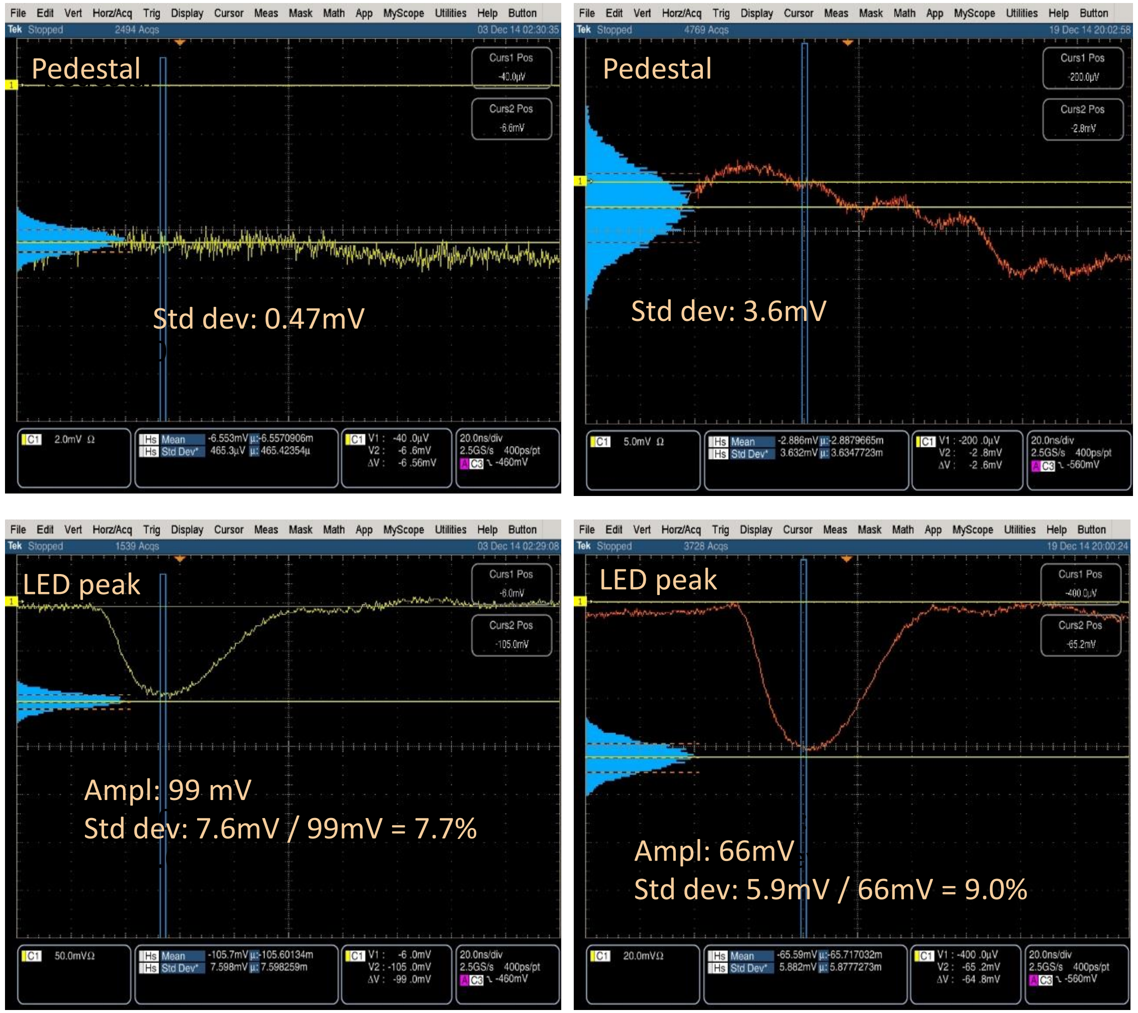
Neutron Damage

- Based on simulations of the STAR hall our best (rough) estimate is that in the sPHENIX IR, we should expect to see approximately $2x10^{10}$ n/cm^2 per Run year
- Radiation Damage Studies done so far:
- Initial SIPMs inserted into PHENIX IR during RUN14
  - 2 Hamamatsu SIPMs - ~3 weeks of beam running time
- Neutron irradiation studies at BNL SSGRIF
  - SiPMs from Hamamatsu, SensL, AdvanSiD, Excelitas, KETEK of various u-pixel sizes –
  - cumulative exposures to $\sim 10^9$ n/cm^2
- Neutron Irradiation studies at Los Alamos (LANSCE)
  - Hamamatsu MPPCs of various u-pixel size-
  - Cumulative exposures to $\sim 7x10^{10}$ n/cm^2

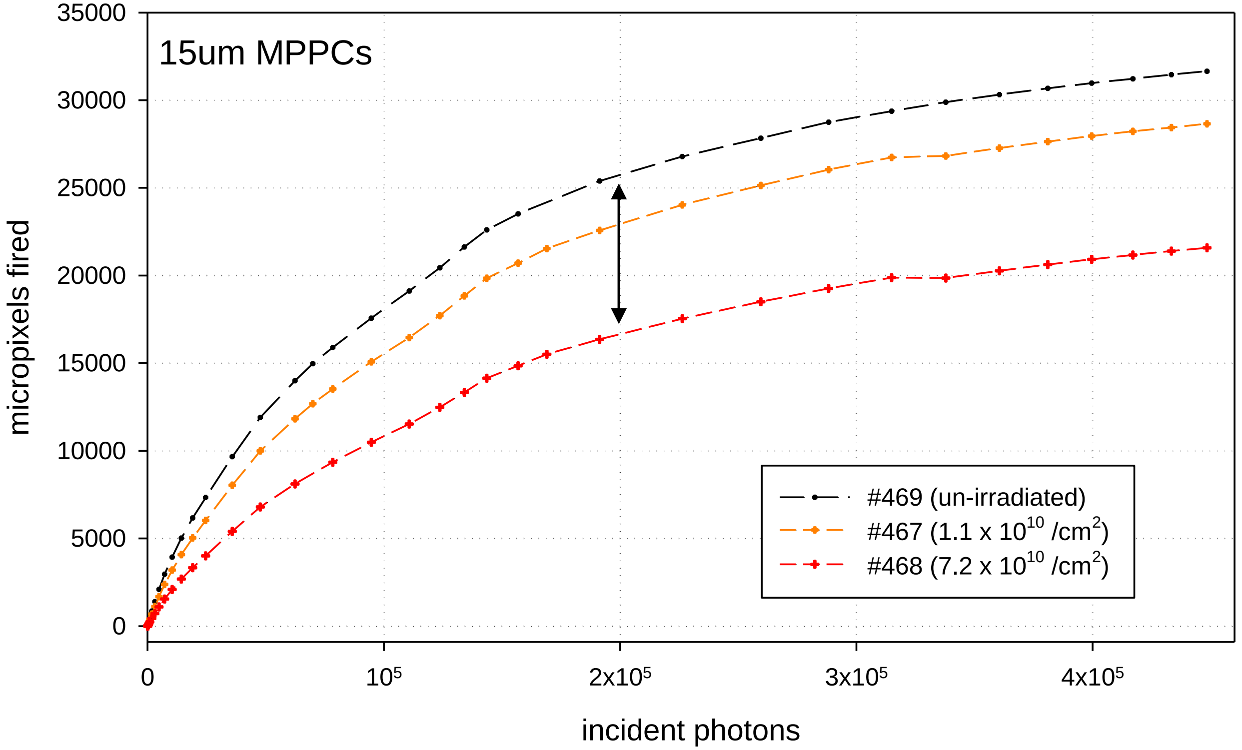
MPPCs + sPHENIX preamp. Pedestal and LED pulser peak measured after irradiation (7.2×10^{10} / cm^2). Hamamatsu 25um u-pixels

Before irradiation

After irradiation



- All devices measured showed an increase in dark current with increasing neutron exposure
- Devices also showed a decrease in dynamic range
- Radiation damage increased dark/pedestal noise, but signals were still readable even after 7×10^{10} neutrons/cm^2



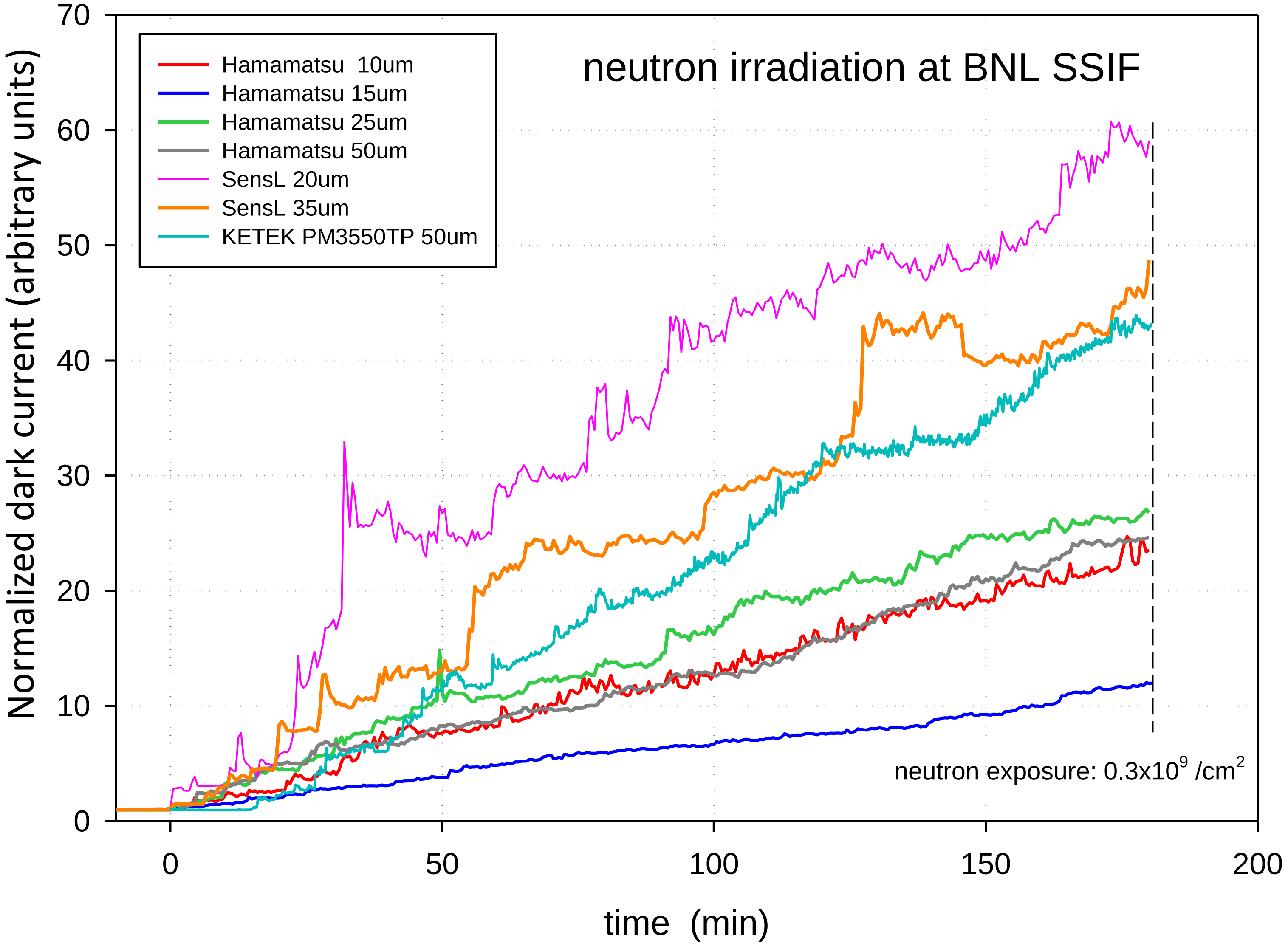
33 % decrease of dynamic range

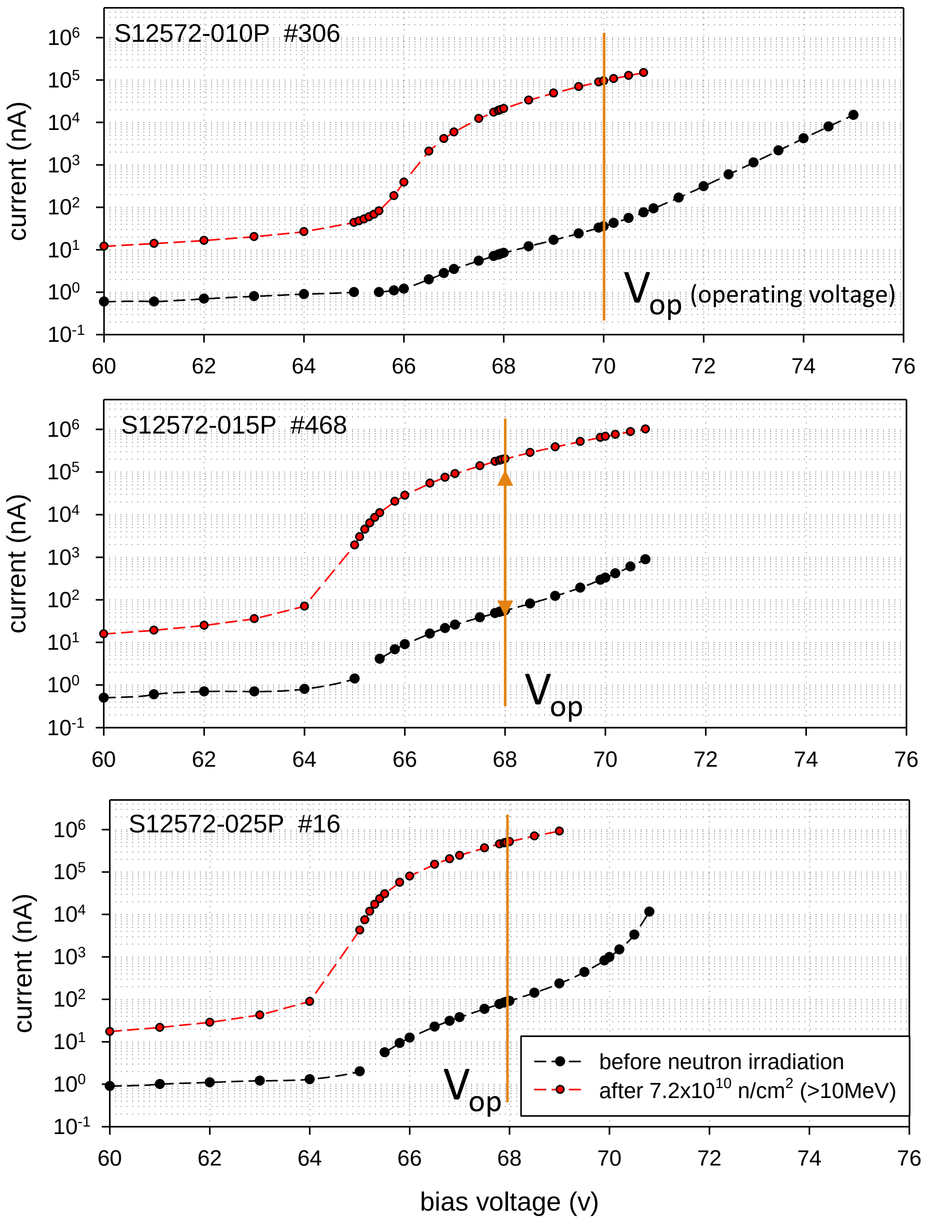
After radiation equivalent of ~3.5 years high luminosity RHIC running

Comparison of SIPMs from different manufacturers.

Neutron exposure to 0.3 x 10^9 /cm^2 Hamamatsu S12572 devices, SensL FC series devices, and KETEK PM3550.

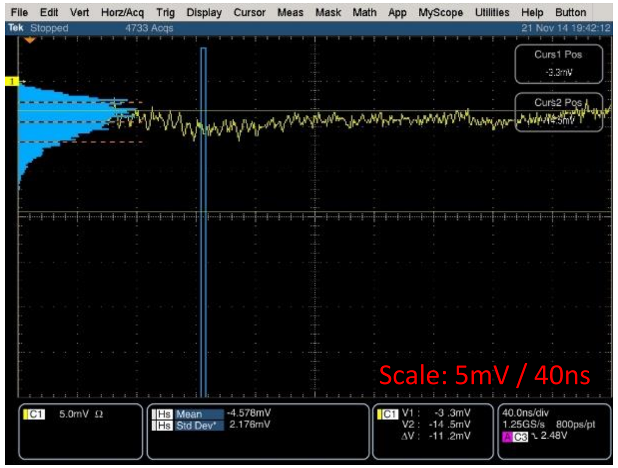
Of the devices tested,
The Hamamatsu -015P showed the least amount of dark current increase

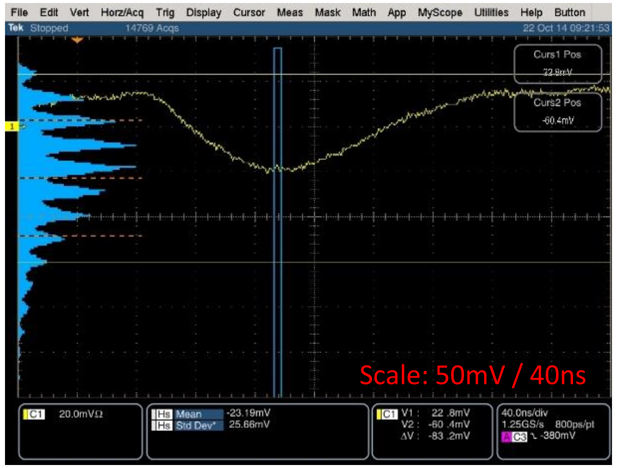


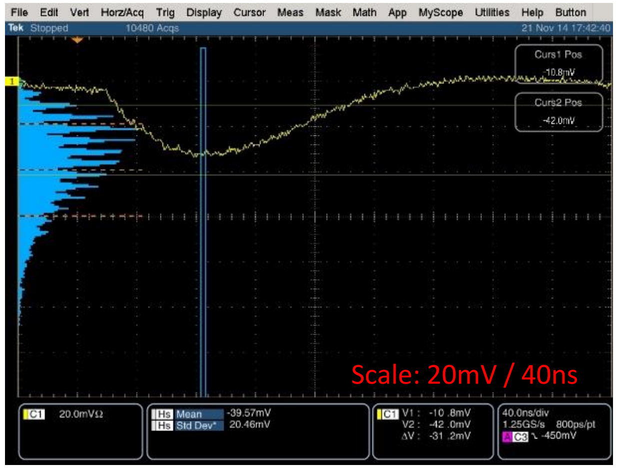


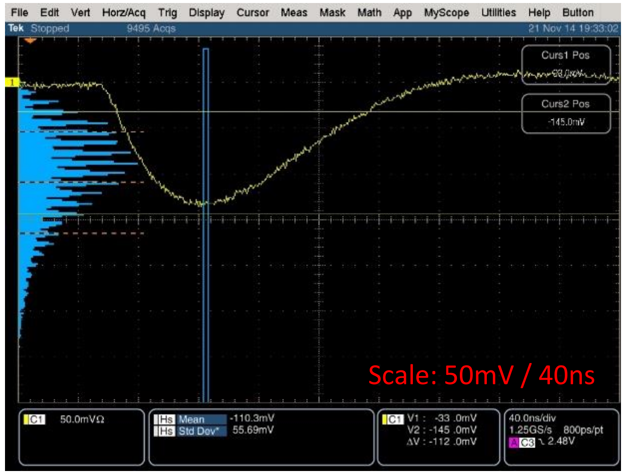
Dark current Increased from 50 nA to 200 uA
Radiation Equivalent of ~ 3.5 years of sPHENIX / high luminosity RHIC running

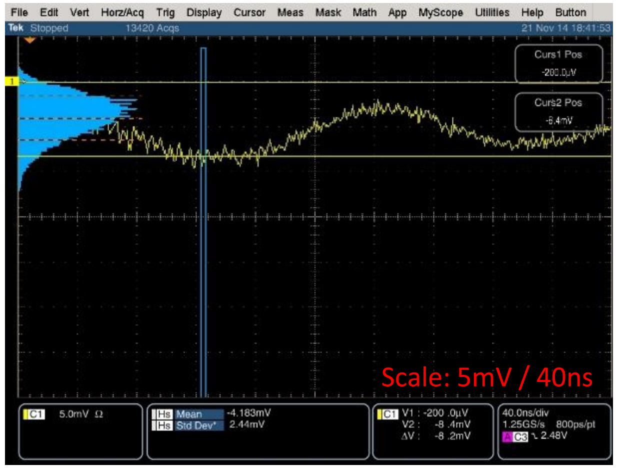
Single pe spectra taken of un-irradiated (top row) and neutron irradiated (bottom row) MPPCs of 4 different pixel sizes.
High gain preamp / low-level LED pulse

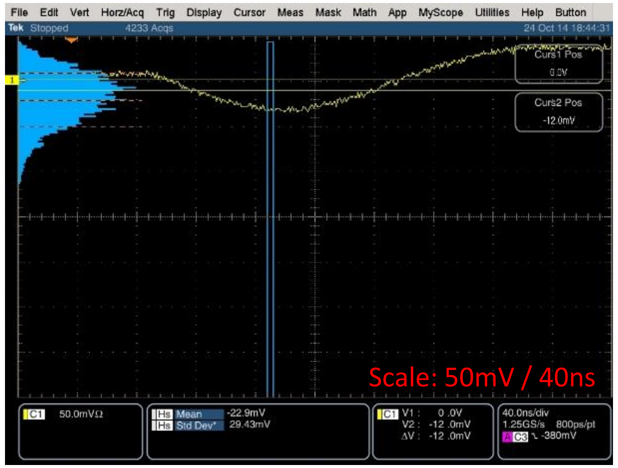


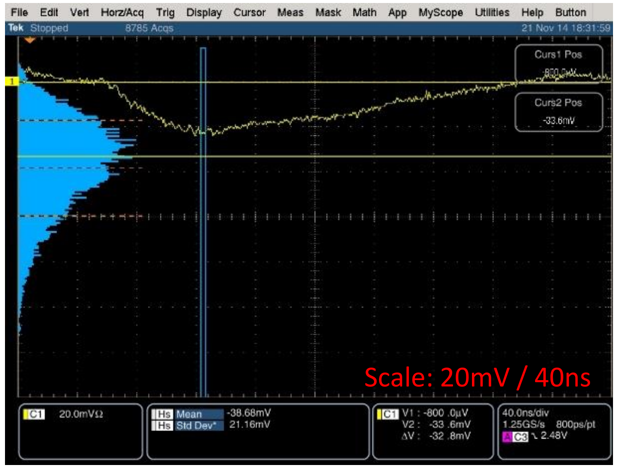


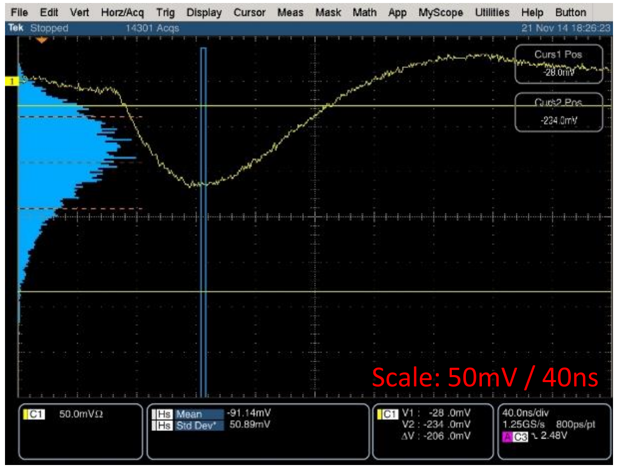






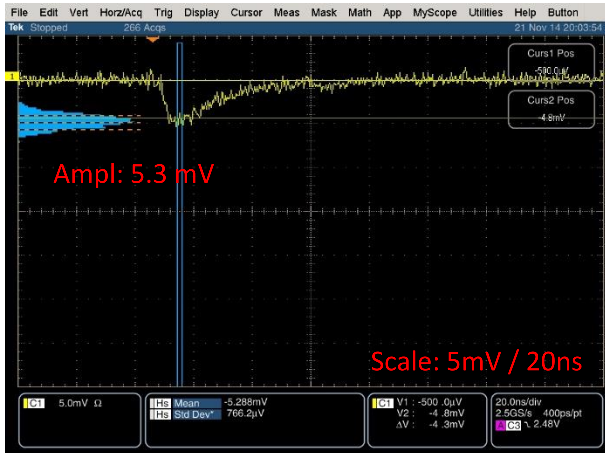


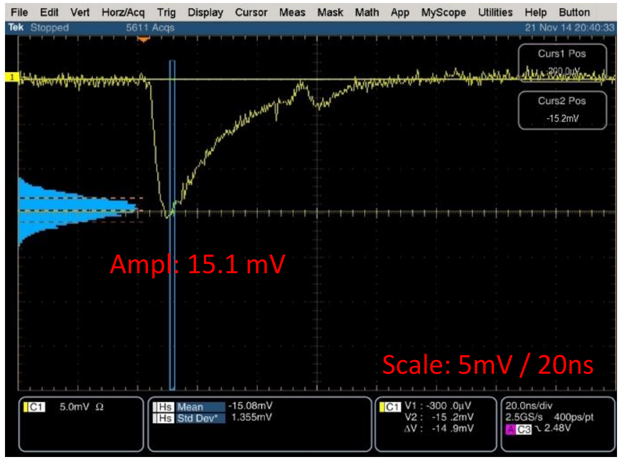


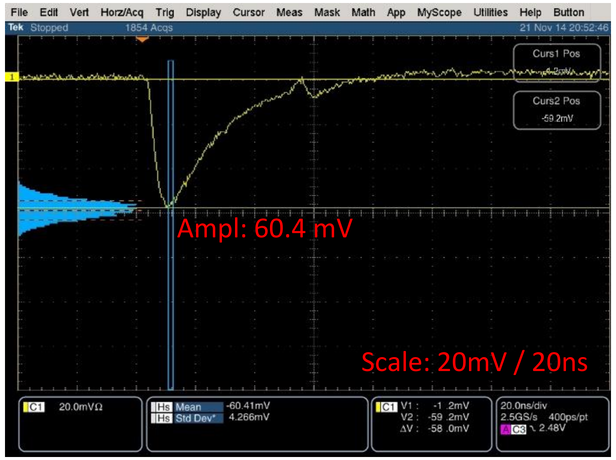


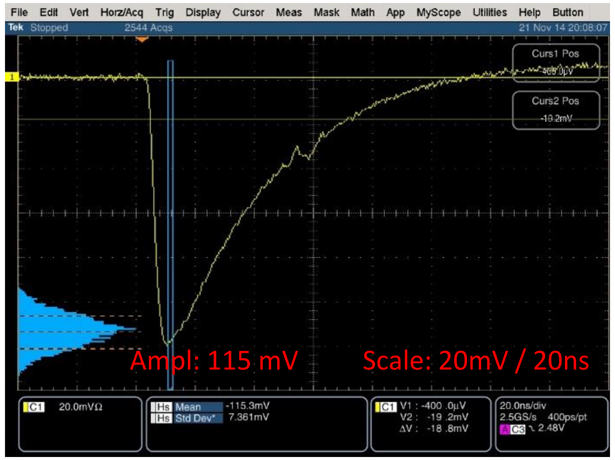
S12572-010P S12572-015P S12572-025P S12572-050P

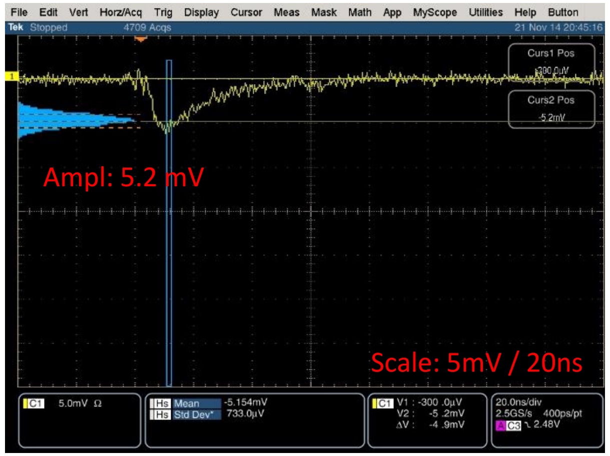
pulse spectra taken of un-irradiated (top row) and neutron irradiated (bottom row) MPPCs of 4 different pixel sizes.
no preamp / larger amplitude LED pulse

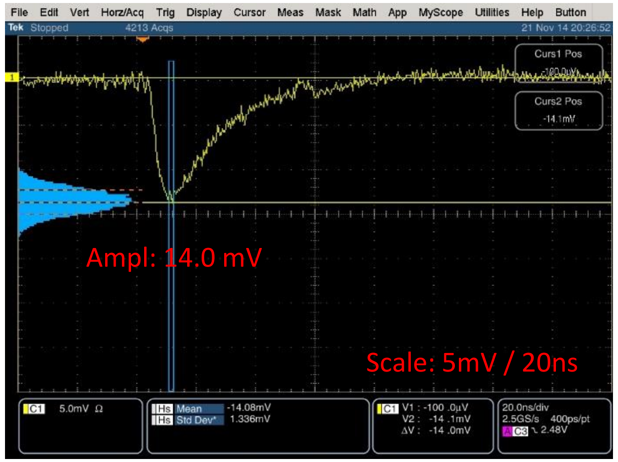


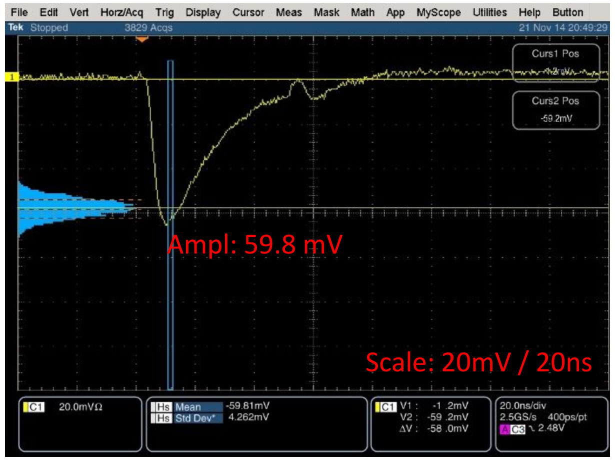


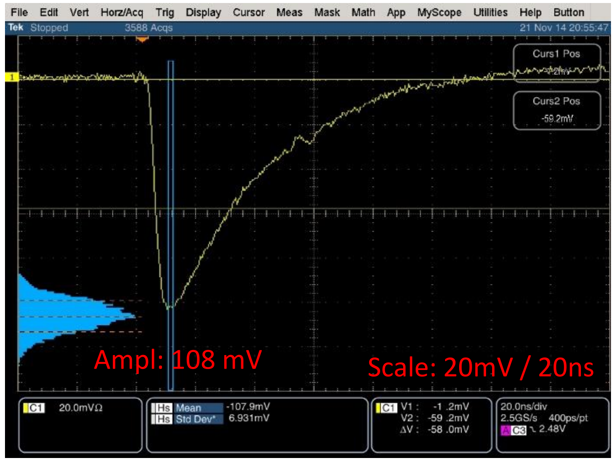












S12572-010P

S12572-015P

S12572-025P

S12572-050P

Issues and Concerns

- Narrowing down choice of sipm – current favorite is the Hamamatsu S12572 -015P

- While the effects of the radiation damage are apparent – increased dark current, increased noise - we need to study how these effects will impact the functional capabilities of the calorimeter

- We have been studying SIPMs as individual devices, we need to do more studies of SIPMs as components of an integrated calorimeter system. This includes: thermal stability, temperature/gain compensation, calibration and gain monitoring, passive summing.

Ongoing work:

Preparing additional radiation damage studies to run in PHENIX IR during RUN 15
- Monitor LED signal amplitudes while radiation damage accumulates
- Monitor change in dark current
- Repeat comparisons of different devices
- Observe effects on passively summed sipms read out though sPHENIX electronics
- shield thermal neutrons

Thermal stability

Optimizing Light collection / coupling of photosensors to absorber

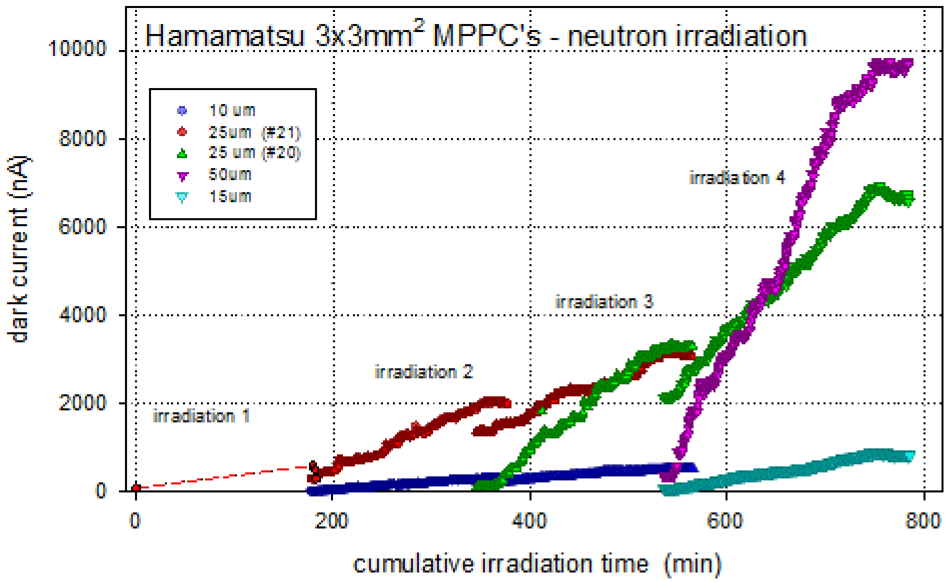
Design/Develop calibration system
- LED or laser pulsed scintillator on back surface, or fiber splitter network to distribute light

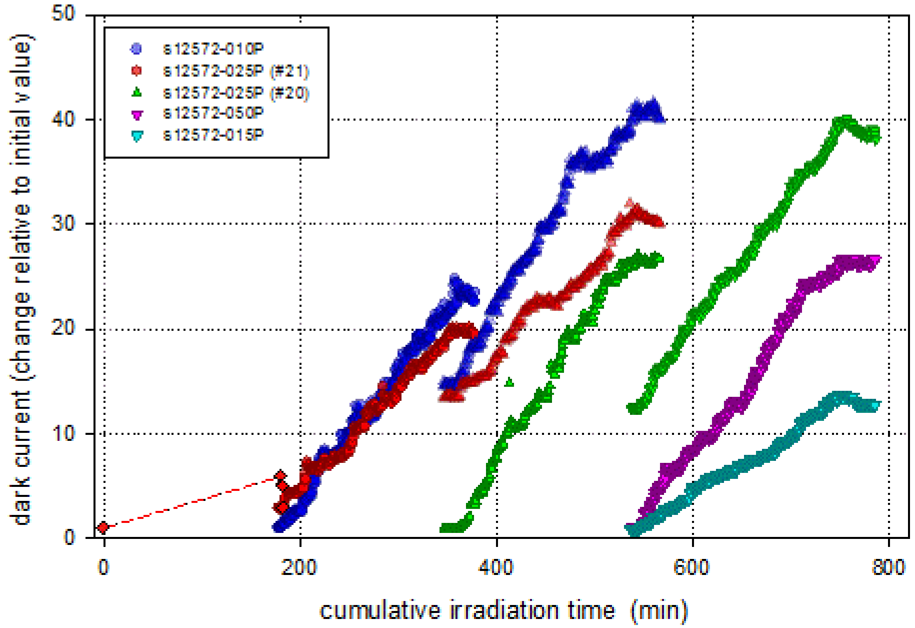
Additional slides

Data compiled from SensL and Hamamatsu data sheets for "typical" devices.

	SensL	SensL	Hamamatsu	Hamamatsu	Hamamatsu
	FC 30020	FC 30035	S12572-025P	S12572-015P	S12572-010P
Vbrkdwn	24.65 V	24.65 V	65 V	65 V	65 V
Vop	27.15 V	27.15 V	68.5 V	69 V	69 V
Gain	1 x 10^6	3 x 10^6	5.15x10^5	2.3x10^5	1.35x10^5
microcell dim	20um	35um	25 um	15um	10um
# microcells	10998	4774	14400	40000	90000
fill factor	0.48	0.64	0.65	0.53	0.33
package dim	4x4mm	4x4mm	4.35 x 3.85mm	4.35 x 3.85mm	4.35 x 3.85mm
peak wl	420 nm	420 nm	450 nm	460 nm	470 nm
PDE	0.24	0.31	0.35	0.25	0.1
I dark	90 nA	200 nA	100 nA	20 nA	30 nA
dark count rate	300 kHz	300 kHz	1000 kHz	1000 kHz	1000 kHz
capacitance	770pF	850pF	320 pF	320 pF	320 pF
temp dependence of gain	-0.9 %/degC	-0.9 %/degC	-4.2 %/degC		

(Data collected from manufacturer’s device data sheets)



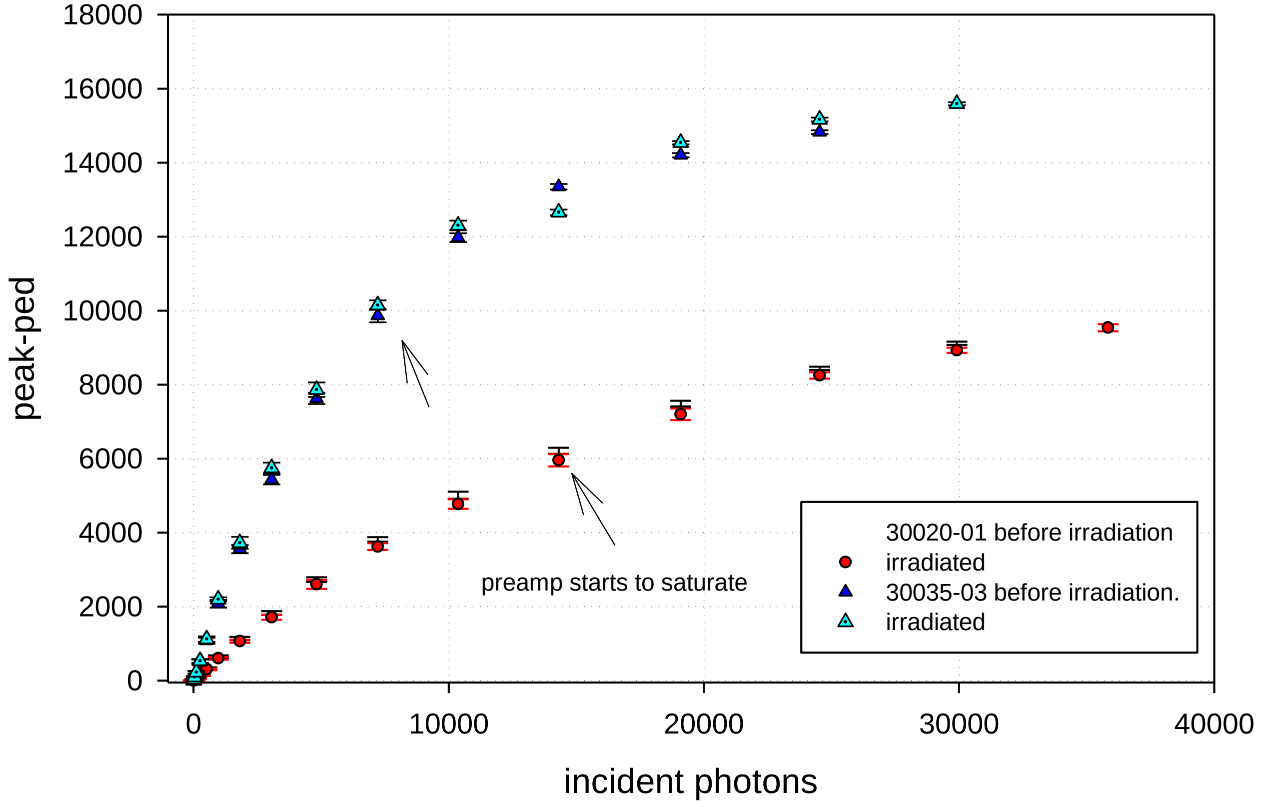


Summary of cumulative neutron irradiations.
each color represents a different device.
Some received repeated exposures.
Each irradiation exposure step is $0.3x10^9$ /cm^2
over 3h. Neutrons are 14MeV.
The top graph shows the absolute dark current, the lower graph shows the change in the dark current for each device, normalized to its initial pre-irradiation value.

SensL FC30020-01 and FC30035-3

LED peak amplitude and sigma before and after neutron irradiation

sPhenix preamp - PHNX-096A Aug 2013



Hamamatsu S12572-025P

Signal integrity at low light levels, irradiated and control device.

(0.3 x10^9 neutrons/cm^2)